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SOME SIMPLE RULES FOR SELF-ADAPTIVE MECHANICAL RECOGNITION OF VOWELS.

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THE VALUE OF THE ACOUSTIC PARAMETERS OF A PHONETIC EVENT VARY FROM SPEAKER TO SPEAKER AND, TO SOME EXTENT, FROM DAY TO DAY. THE ABSENCE OF STABLE INVARIANTS IN SPEECH PRODUCTION IMPLIES THAT A COMPUTER MUST BE SELF-ADAPTIVE IN ORDER TO RECOGNIZE THE PHONETIC EVENTS OF DIFFERENT SPEECH PRODUCTIONS. SELF-ADAPTATION, HOWEVER, REQUIRES THAT PHONEME SEPARATION AND CLASSIFICATION BE ACCOMPLISHED BY THE USE OF SIMPLE BOUNDARIES AND SIMPLE CHANGES IN THESE BOUNDARIES, WHILE MAINTAINING THE REQUISITE ACCURACY. THIS EXPERIMENT PRESENTS DATA THAT INDICATE THAT VOWELS MAY BE CLASSIFIED BY USING SIMPLE BOUNDARIES IN THE F1-F2 PLANE IF SUFFICIENT CONTROL OVER THE SPEECH PRODUCTION HAS BEEN EXERCISED. FORMANT LOCATIONS OF 176 PRODUCTIONS OF EIGHT VOWELS FOR NINE SPEAKERS ARE PRESENTED IN WHICH IT IS SHOWN THAT SUITABLE ACCURACY OF CLASSIFICATION IS OBTAINED BY A BOUNDARY OF CONSTANT F1 AND A BOUNDARY OF CONSTANT F2. THE SUGGESTION IS MADE THAT THESE BOUNDARIES, WHILE BASED ON VOWEL PRODUCTION, MAY BE OF SIGNIFICANCE IN VOWEL PERCEPTION. THIS PAPER IS PUBLISHED IN "STUDIES IN LANGUAGE AND LANGUAGE BEHAVIOR, PROGRESS REPORT IV," BY THE CENTER FOR RESEARCH ON LANGUAGE AND LANGUAGE BEHAVIOR, UNIVERSITY OF MICHIGAN, 220 EAST HURON STREET, ANN ARBOR, MICHIGAN 48108. (AUTHOR/AMM)

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Some Simple Rules for Self-Adaptive Mechanical Recognition of Vowels.[1]

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The value of the acoustic parameters of a phonetic event vary from speaker to speaker and, to some extent, from day to day. The absence of stable invariants in speech production implies that a computer must be self-adaptive in order to recognize the phonetic events of different speech productions. Self-adaptation, however, requires that phoneme separation and classification be accomplished by the use of simple boundaries and simple changes in these boundaries, while maintaining the requisite accuracy. This experiment presents data that indicate that vowels may be classified by using simple boundaries in the F1-F2 plane if sufficient control over the speech production has been exercised. Formant locations of 176 productions of eight vowels for nine speakers are presented in which it is shown that suitable accuracy of classification is obtained by a boundary of constant F1 and a boundary of constant F2. The suggestion is made that these boundaries, while based on vowel production, may be of significance in vowel perception.

The historical approach to the recognition of speech by computer has been to determine and measure the invariant properties of speech which reside in the acoustical signal. Unfortunately, about the only invariability in speech is its variability. The listener is apparently not disturbed by this variation, but a digital computer must operate with discrete and precise information. In order to determine this precise information it seems possible that an examination of the sources of parameter variability will reveal mechanical procedures for accounting for the variability, i.e., it should provide clues to various normalization procedures. The object of a mechanical speech recognizer is to present a written equivalent of a speech input. Furthermore, the computer output is to approximate as closely as possible the transcribing behavior of at least one listener. The recognizer should attain this close approximation in the face of the same variability that confronts the listener.

A classic representation of the first and second formant variability for the vowels of English is given by 76 speakers in the Peterson-Barney (1952) study.

Insert Fig. 1 about here

Figure 1 presents formant frequency location as a function of vowel label for ten vowels pronounced by 76 speakers in a /h - d/ environment. The first observation to be made concerning these data is the considerable vowel overlap. That is, there are vowels which have the same or nearly the same first and second formants, but which have different labels. These vowels are recognized by a listener as distinct (at least under certain conditions), which indicates that the vowels are not completely characterized by absolute physical properties.

A second observation shows that, although the overlap would produce some errors, a reasonable recognition accuracy can be attained by using complicated boundaries, such as the oval contours shown in Fig. 1. This cannot be an acceptable solution to the problem of mechanical recognition, however, since each vowel was produced in the same consonantal environment. Any change in this context tends to increase the variability and decrease the accuracy. Even more important is the failure of this boundary set as a simulation of human vowel perception. It is easy to see that the accuracy of recognition based on boundaries such as these would vary greatly from speaker to speaker to a degree not present among human listeners.

One of the first steps in an investigation of mechanical recognition is the determination of the sources of variability and their relative importance in scattering the data. Two sources of parameter scatter have been mentioned, inter-speaker differences and phonetic environment. The relative effect of the sources of variability may be measured by the degree of parameter overlap, i.e., the ratio of different phonetic items with similar physical properties to the separable items.

In order to illustrate how this ratio is used to compare inter-speaker variability with contextual effects, we can examine the scatter of vowel data of 76 speakers for the /h - d/ context and compare it with the scatter of data of one speaker in all possible CV and VC contexts.

Insert Fig. 2 about here

The contours enclosing vowel production areas of a single speaker are generally smaller, and the formant overlap is less. This fact suggests that differences between speakers are greater than differences in phonetic contexts.

Any extension of the speech data samples, say, to longer words or continuous speech, would increase the variability, as is shown by Fig. 3, taken from a study by Shearme and Holmes.

Insert Fig. 3 about here

The overlap portrayed here is extreme. Note particularly the vowels /i/ and /I/. A computer cannot separate these two vowels on the basis of F1 and F2 alone. This fact would be discouraging for a program in mechanical recognition, except that the cause of the overlap and parameter shift is not shown. In other words, the control expressed in this experiment was not sufficient to determine the conditions of the vowel space. Not only is the direction and degree of parameter shift important, but also the stability and reproducibility of the shift and the factors responsible for the shift. This program in mechanical recognition is an attempt to design experiments in which only one possible cause of variation at a time can operate. The source of variation then becomes the independent variable, and the distribution and shift of the vowel parameters are the dependent variables. It is hoped that the resulting parameter shift from each cause is a stable shift and that each source of variability is independent. Thus, if a given consonantal environment tends to lower the second formant of speaker A in a CVC monosyllable, then the same environment should tend to lower F2 for the continuous speech of speaker B. The feasibility and economy of a mechanical speech recognizer depend on the consistency of this effect.

This program, then, is a series of experiments in speech production in which only one source of parameter variation, the independent variable, is allowed to change, if at all possible. Note that not all of the sources of production variability are known. The factors that do contribute to a variation of parameters that are known include: the speaker: the speaker's sex, physical condition, age, articulatory configuration; the time of day; the instructions given the speaker; the list of material (whether it is to be read, repeated or memorized and so forth, or whether it is continuous speech or isolated words); the acoustic conditions at recording; the equipment used; the method of measuring acoustic parameters; and many others.

The first step is to see if these sources of variability can be held constant. Every one of the above factors was held constant, except that the speaker attempted to duplicate his production on three different days. The first two were a week apart, and the last, two days apart, Thus, the same speaker on three different occasions was given the same instructions to repeat the same CVC word list in the same room, on the same recorder, and so on. The data were processed for all three readings at the same time and the measurement of parameters was carried out by digital computation. This is perhaps the maximum control that can be exercised on speech production short of achieving reinforcement control, and it is not yet apparent that that much control is desirable in a speech recognition program.

Insert Fig. 4 about here

Figure 4 shows the third trial of speaker DVY. Note the position of the contour enclosing most of the vowel /U/. It is adjacent to and nestled between /ʌ/ and /ɔ/.

Insert Fig. 5 about here

Figure 5 shows the same speaker's vowel production the following week. /U/ and /ɔ/ are more widely separated. In addition, the contour enclosing the vowel /I/ is larger.

Insert Fig. 6 about here

Figure 6 shows the same speaker two days later. If Fig. 5 and Fig. 6 were superimposed, the differences would be much clearer. For the most part, the vowel areas are the same. There are some problems, however. When both sets of data are taken together, there is a large degree of variation and overlap between the vowels /ʌ/ and /ɛ/. These vowels did not overlap on individual days. Optimal recognition of this speaker's vowels depends, then, upon shifting the boundaries slightly from day to day. In addition, the day-to-day change in the distribution of the production parameters may be greater for more complex stimuli. So far, these data indicate that given a single set of conditions of vowel production, including the requirement that the production of the speech does not spread out over a long time, the overlap and variability are small

enough that the computer optimally recognizes the vowels. Every separate production of the vowels may, however, require a new set of decision boundaries. In the recognition of continuous speech it may not be possible to find stable boundaries, even in the same speech production.

Any change in the factors of speech (mentioned earlier), which in turn implies a different production, requires a change in the decision boundaries. The problem of mechanical speech recognition is to find a means of determining proper boundaries automatically, that is, on the basis of the properties of each separate speech production. Complex boundaries (complex in terms of the physical variables) can be programmed into the computer, but the need to shift the boundaries for each separate production almost demands that the decision boundaries be very simple. Some perceptual studies also indicate that very complex decisions by listeners are not made. The future possibilities of mechanical recognition depend upon finding simple boundaries which can be easily shifted and yet which yield adequate results.

Speech communication takes place between at least two persons, implying that perception, as well as production, is important to the process. Thus, recognition boundaries must be related to the perceptual referents of at least one listener. This point is fully appreciated and no attempt is made to slight its importance. However, to paraphrase Jakobson, a person speaks in order to be heard, in order to be understood. Therefore, some initial decisions can be formed on the basis of the distributions of the parameters of production. Nevertheless, the only criterion of success of a mechanical recognizer is that it approximates the recognition behavior of at least one listener, and any mechanical scheme must be evaluated in these terms.

With this description of the problem we may now look at some more formant positions of CVC monosyllables.

Insert Fig. 7 about here

Figure 7 is a plot of F1 and F2 for 84 words produced by speaker JRP at one sitting. These 84 words are so generated that all possible CV and VC combinations are present. The various ovals surrounding production values of F1 and F2 are drawn to include nearly all voicings of the same vowel and yet remain non-overlapping. These ovals are complex, but ideal or optimum as far as accuracy is concerned. They provide for the lowest error-rate, but they are

probably not realistically related to perception and they are not simple enough to avoid very complicated programming changes when production conditions change.

Jakobson, Fant and Halle (1952), suggest what to look for when examining the distribution of speech parameters. For example, in the discussion of the distinctive feature compact/diffuse, they say: "In the case of vowels this feature manifests itself primarily by the position of the first formant: when the latter is higher (i.e., closer to the third and higher formants), the phoneme is more compact." Now, since this is a binary feature, the statement seems to imply that, were F1 alone plotted, there would be a bimodal distribution in production and if F1 alone were varied, there should be a [illegible]y characteristic in the perceptual behavior. In fact, many critics of the distinctive feature theory insist that such a bimodal distribution is a necessity of the theory. However, Jakobson and Halle go on to say: "The opposition compact vs. diffuse in the vowel pattern is the sole feature capable of presenting a middle term in addition to the two polar terms. On the perceptual level, experiments that obtained such middle terms through the mixture of a compact with the corresponding diffuse vowel seem to confirm the peculiar structure of this vocalic feature . . . ."

In later discussions Halle prefers two binary decisions to a single tertiary feature, and talks of vowels which are noncompact and nondiffuse. This distinction between tertiary and binary is merely academic unless it makes a testable difference at some level. Furthermore, Jakobson and Halle refer only to the vowels in [bat], [bet], [bot], [but], [boot], and [bit], not including the vowels [bought] and [beet]. Later, Halle (1957) and Jakobson and Halle (1961) included the feature tense vs. lax and these two vowels.

At this point their system has eight vowels divided into four tense vowels: four lax, four acute, four grave, four diffuse, and four compact.

In addition, Halle also considers the vowels /e/ and /o/, for which he develops the distinction noncompact-nondiffuse, although upsetting the symmetry and efficiency of the feature system just a bit.

Most of the data included in this study came from speakers with a midwest dialect; it was noted from the data that the vowels /e/ and /o/ are physically more like simple diphthongs. It is interesting to contemplate the effect of describing these two sounds in the system as diphthongs characterized by a transformation from a compact to a diffuse vowel. In anticipation of the value of this viewpoint, the vowel F1-F2 plane has been plotted without including /e/ or /o/. This change in concept eliminates the need for a noncompact-nondiffuse distinction and reduces the number of features to three, the least number required for eight vowels.

It is not certain that the distribution of the production parameters in a binary fashion is necessary for the validity of the feature theory. However, it is a fact that the monosyllable data do suggest a two-valued distribution along the first formant. If it is possible to describe /e/ and /o/ by their transition of the first formant, then we should achieve a bimodal distribution along F1 for the remaining eight vowels.

Figure 7 shows that it <u>is</u> possible to perform a Halle-type bisection, dividing the diffuse vowels from the compact vowels on the right according to the value of the first formant. The vertical dotted line represents a line of constant F1. If this is chosen as a boundary for the compact/diffuse decision, there will occur three compact errors for an accuracy of about 96 percent. If we move this boundary to the right 25 cps, we will have three diffuse errors and the same accuracy. This boundary satisfies the requirements of simplicity and ease of change by computer. It is also accurate enough for computer recognition, and this accuracy may improve, pending the results of the listening tests.

Insert Fig. 8 about here

Figure 8 shows the F1-F2 vowel distribution for speaker GDA. Again a line of constant F1 provides an accurate division of compact vs. diffuse vowels. There are four errors, and the accuracy of the decision is greater than 95 per cent. The frequency of the boundary is approximately 435 cps, down from the value of 475 cps for speaker JRP in Fig. 9.

Insert Fig. 9 about here

Speaker GWH. One diffuse error at a boundary of 510 cps or one compact error at a boundary of 540 cps are found.

Insert Fig. 10 about here

Speaker CS. Two compact errors at a boundary of 510 cps are observed.

Insert Fig. 11 about here

Speaker JLK. Two compact and three diffuse errors at a boundary of 485 cps, for an accuracy of about 94 per cent, are obtained.

Insert Fig. 12 about here

Speaker DVY Trial No. 2. No errors for a boundary from 500 to 550 cps are found.

The accuracies obtained by a decision boundary set at a constant first formant are excellent. An earlier study (Hughes & Hemdal, 1965) also has shown that perhaps as many as 50 per cent of the computer errors were also production errors. That is, listener tests indicated that nearly half of the vowels in error were identified differently than the speaker intended. Of course, much of the parameter measurement was performed automatically by a computer, and this may be another source of error.

Fant (1960), in a study of the F-patterns of compound tube resonators and horns, calculated the hypothetical formant frequencies of an open tube of length 17.6 cm., approximately equal to the average length of the male vocal tract. This tube, with an average speaker's cross-sectional area, produces a first formant of 500 cps which Fant refers to as the neutral reference. It may be interesting to speculate on a possible connection between this reference and the clustering of the compact/diffuse boundary around 500 cps.

The only change in the conditions of production were the speaker and the time of production. A good case is made for using a line of constant F1 for the compact/diffuse boundary in a computer recognition program, at least for monosyllables. But the frequency value of this line changes from speaker to speaker. Is it constant for a given speaker, i.e., is this boundary one of the invariants of speech production? To answer the question, an examination was made of the productions of speaker JFH in 1964 and in 1966, and the production of speaker DVY in 1966, a week apart and two days apart. In this latter set of three repetitions, all possible control on the conditions of production was maintained, except the separate occurrences.

Insert Fig. 13 about here

Figure 13 presents the 1966 data of speaker JFH. There are six compact errors resulting from a boundary placement at 465 cps, or eight diffuse errors at 450 cps.

Insert Fig. 14 about here

Figure 14 presents the 1964 data of the same speaker. There are five diffuse and three compact errors at a boundary of 510 cps, a difference of around 50 cps in the distribution of the separation of vowels along F1. This is a significant change in the frequency of the boundary, since error rates increase rapidly for small changes in this value. These data were taken two years apart, so it is necessary to determine if this is a long term shift in values and whether such changes occur on a day to day basis. For this answer we go to the three repetitions of speaker DVY, Trials No. 3, No. 4, and No. 5 in Figs. 4, 5, and 6.

Figure 4 shows the greatest error rate. The minimum error is about 15 per cent, primarily because of proximity of /U/ to /ɔ/. The best boundary does appear to be around 520 cps.

Figure 5 yields five errors at 540 cps for an accuracy of 94 per cent.

Figure 6 shows three errors when the boundary is set again at 520 cps. Although the error rates vary considerably, the location of the compact/diffuse boundary does not. If a frequency of 520 cps is chosen and all three trials lumped, the overall accuracy is greater than 90 per cent.

For mechanical recognition the most useful boundaries between vowel groups are those that are simply expressed in terms of the physical variable of measurement primarily because, as mentioned earlier, these boundaries have to be shifted automatically for each new speaker. Both the shift and the information about the speaker which is needed for the shift should be easily obtainable. Thus, a compact/diffuse boundary of a line of constant F1 is particularly attractive and the accuracy is very good. This tempts one to speculate on the significance of the bimodal cluster of data and to inquire into a possible relation to vowel perception. Future studies with synthetic vowels will be conducted in an effort to determine if a relation exists between this production boundary and perceptual boundaries.

This result also prompts one to ask whether there are other similar production distributions that will allow simple boundaries for other features.

Consider the feature acute vs. grave. Jakobson and Halle consider F2 to be the primary determiner of acute vs. grave, and they suggest as a measure for this feature the ratio of the difference between F1 and F2 to the difference of F2 and F3. The ratio corresponds to a boundary sloping up from left to right.

A straight line of gentle slope in this region will divide the acute from the grave vowels in Fig. 7 with an accuracy of 98 per cent. The left-most vowel above this boundary is an /ɪ/ which is differentiated from all other vowels in having a relatively low third formant. This vowel need not be included in the grave/acute boundary discussion. Therefore, a boundary of a line of constant F2 may be used as the grave/acute boundary with no increase in error. Again it is necessary to see if the boundary is applicable across a speaker population. Returning to previous figures, the following grave/acute boundaries and accuracies are obtained:

In Fig. 8 (Speaker GDA) Constant F2=1325 cps, yields no errors.
In Fig. 9 (Speaker GWH) F2=1530 cps, three errors, 96 per cent accurate.
In Fig. 10 (Speaker CS) F2=1400 cps, ten errors, 88 per cent accurate.
In Fig. 11 (Speaker JLK) F2=1400 cps, one error, 99 per cent accurate.
In Fig. 12 (Speaker DVY No. 2) F2=1390 cps, three errors, 96 per cent accurate.
In Fig. 13 (Speaker JFH 1966) F2=1525 cps, seven errors, 91 per cent accurate.
In Fig. 14 (Speaker JFH 1964) F2=1525, four errors, 95 per cent accurate.

The conclusion again may be stated that it is possible to satisfy the requirements of simplicity and maintain sufficiently high accuracy. It is also interesting to note that the grave/acute boundary is very close to 1500 cps, the second formant calculated by Fant for the neutral reference vowel based on average vocal tract dimensions. Perhaps the measurement of an individual's neutral vowel is related to the location of this boundary junction.

In this study it has been shown that parameter variability in vowel production can be controlled. It has also suggested several methods of describing the characteristics of production. We do not know yet whether these simple boundaries have any relationship to vowel perception. Experiments conducted

with synthetic vowels should give us this information. If we consider that the first and second formants are perceptual continua, then the two simple boundaries imply that the listener attends to these continua independently and need only make a binary decision on them.

It should be emphasized that these boundaries constitute only a model of recognition of vowels in carefully pronounced nonsense syllables. They are parameters of production under these conditions and not of perception. In addition, they may not be extendable to the production of actual words or continuous speech; however, it will be a part of our methodology to attempt to relate each separate source of parameter variability to these simple boundaries.

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Footnote

[1]This report was presented in another form as an address at the Conference on Language and Language Behavior, CRLLB, University of Michigan, Ann Arbor, October, 1966.

Figure Captions

Fig. 1. Distribution of vowel production values on F1-F2 plane for 76 speakers (from Peterson & Barney study).

Fig. 2. Distribution of vowel production values on F1-F2 plane for speaker DVY, Trial No. 1.

Fig. 3. Distribution of vowel production values on F1-F2 plane for continuous speech of one speaker (from Shearme & Holmes study).

Fig. 4. Distribution of vowel values on F1-F2 plane for speaker DVY, Trial No. 3.

Fig. 5. Distribution of vowel production values on F1-F2 plane for speaker DVY, Trial No. 4.

Fig. 6. Distribution of vowel production values on F1-F2 plane for speaker DVY, Trial No. 5.

Fig. 7. Distribution of vowel production values on F1-F2 plane for speaker JRP.

Fig. 8. Distribution of vowel production values on F1-F2 plane for speaker GDA.

Fig. 9. Distribution of vowel production values on F1-F2 plane for speaker GWH.

Fig. 10. Distribution of vowel production values on F1-F2 plane for speaker CS.

Fig. 11. Distribution of vowel production values on F1-F2 plane for speaker JLK.

Fig. 12. Distribution of vowel production values on F1-F2 plane for speaker DVY, Trial No. 2.

Fig. 13. Distribution of vowel production values on F1-F2 plane for speaker JFH, 1966.

Fig. 14. Distribution of vowel production values on F1-F2 plane for speaker JFH, 1964.

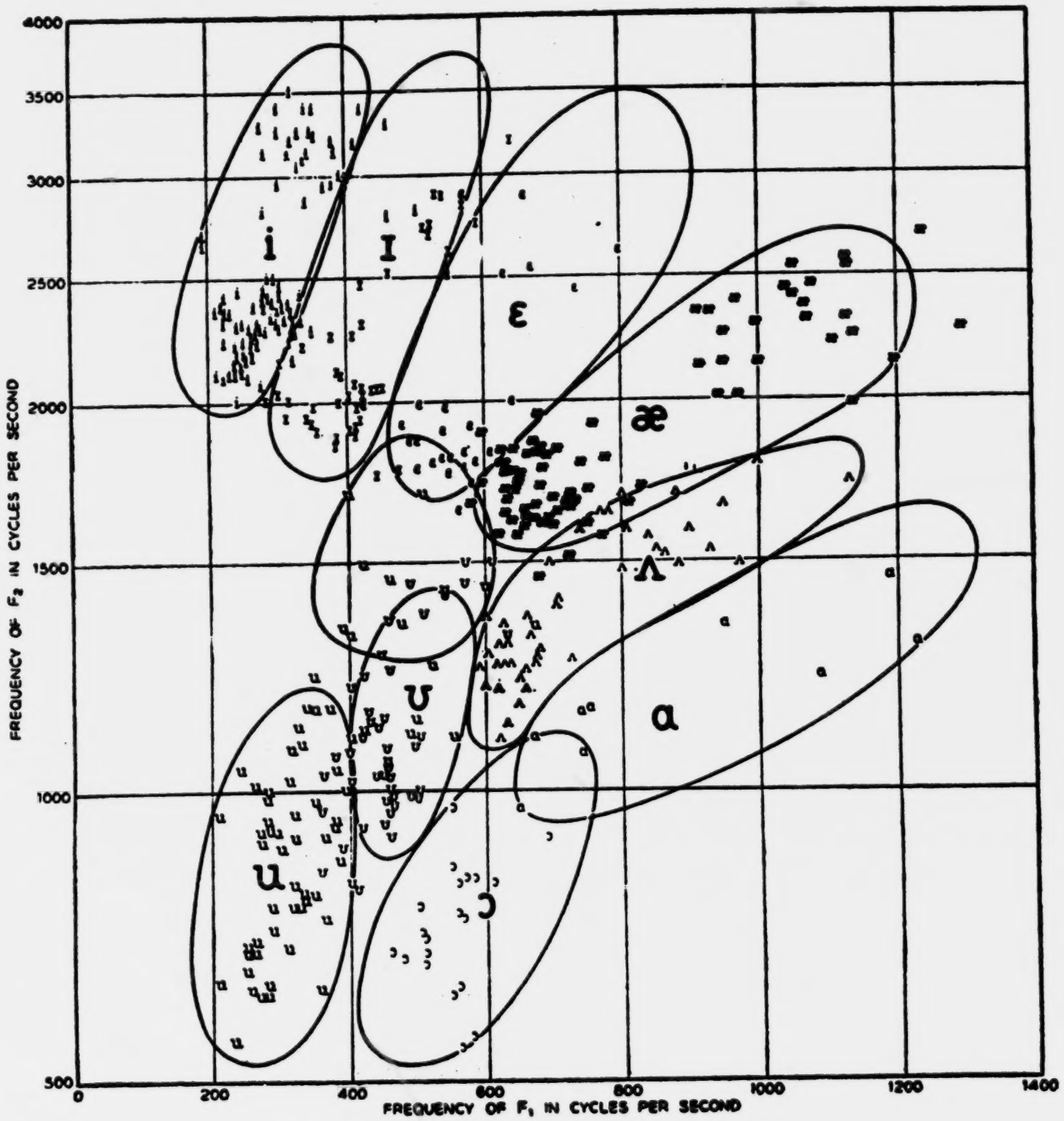
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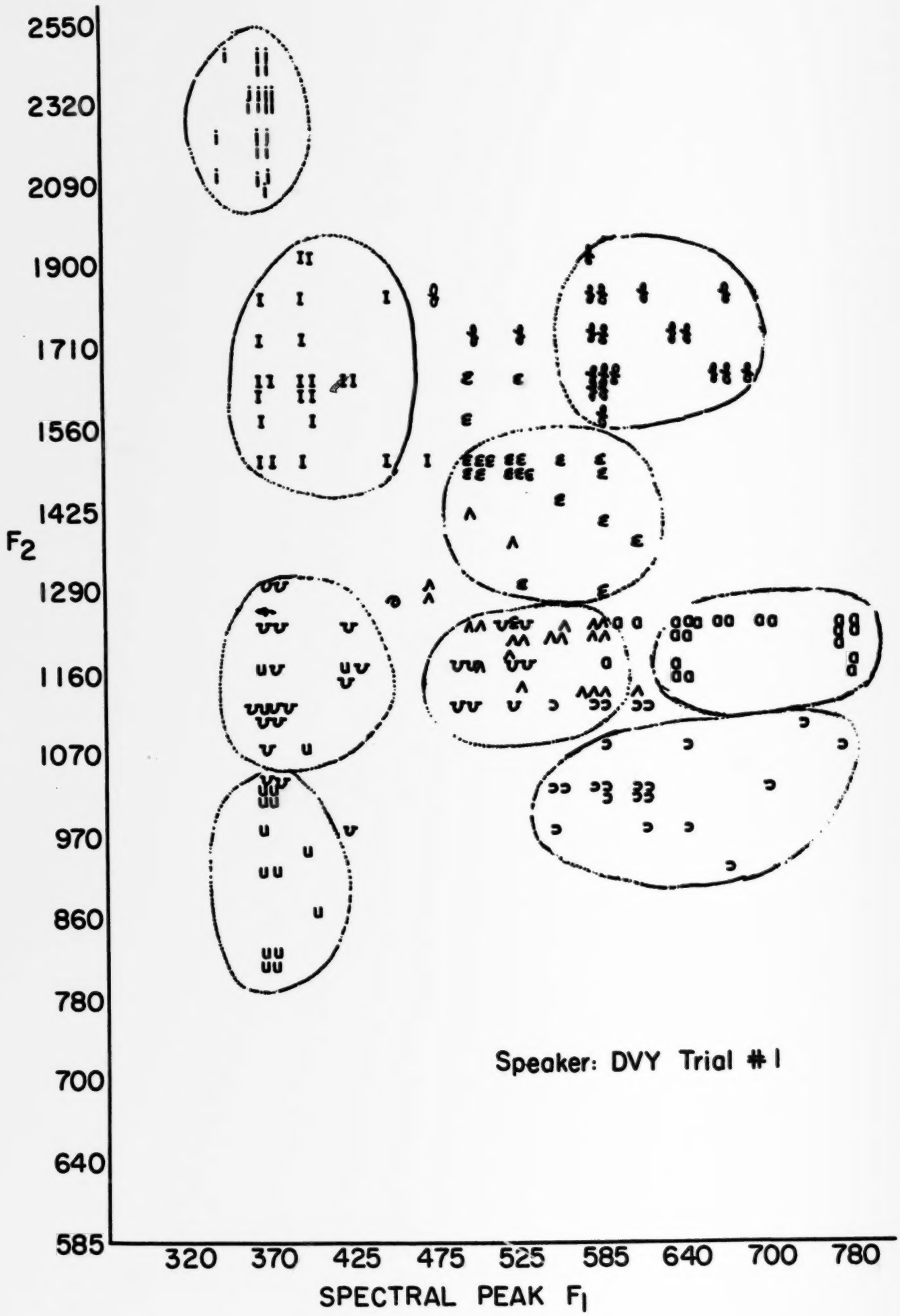
Fig. 1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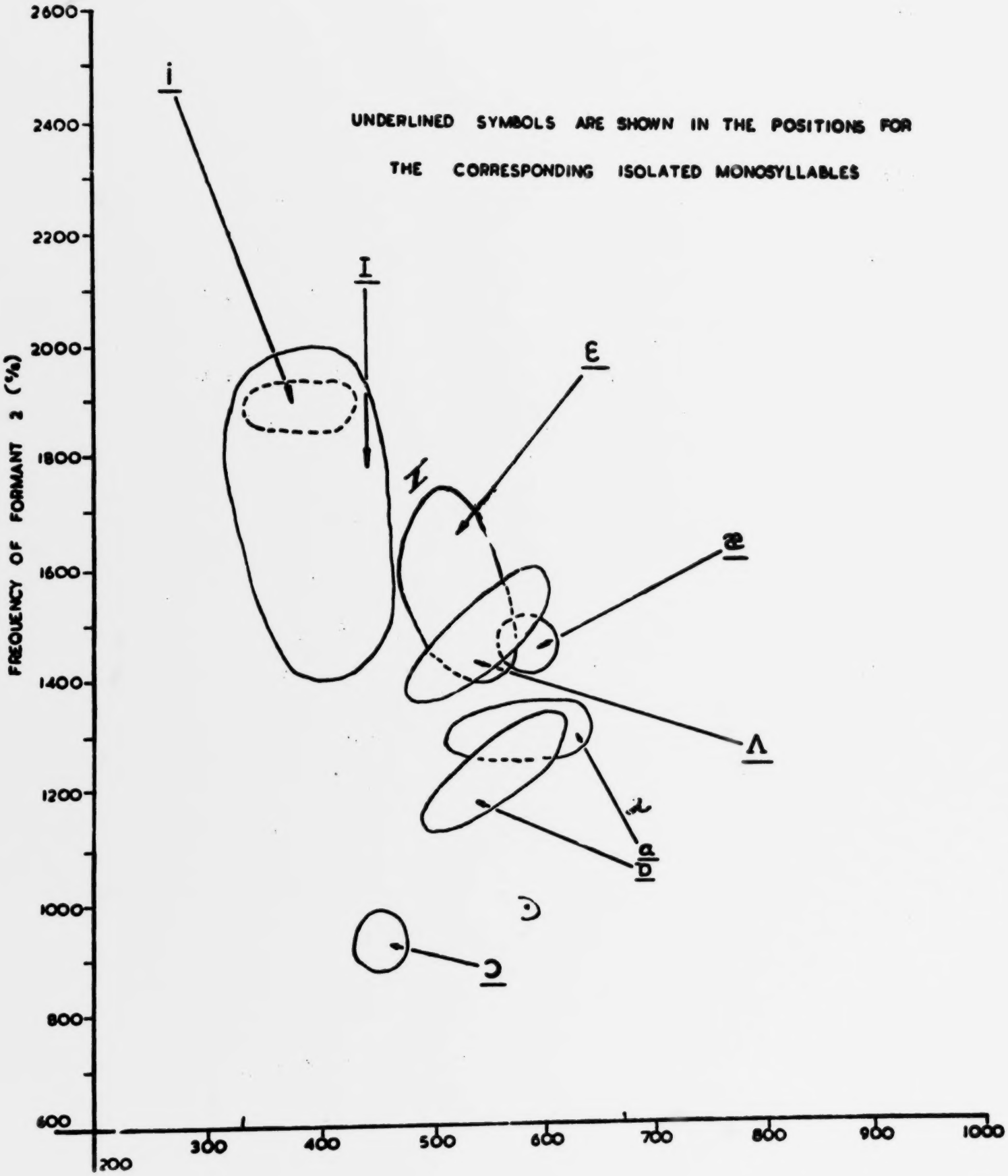
SPECTRAL PEAK F1
Speaker: DVY Trial #1

Fig. 2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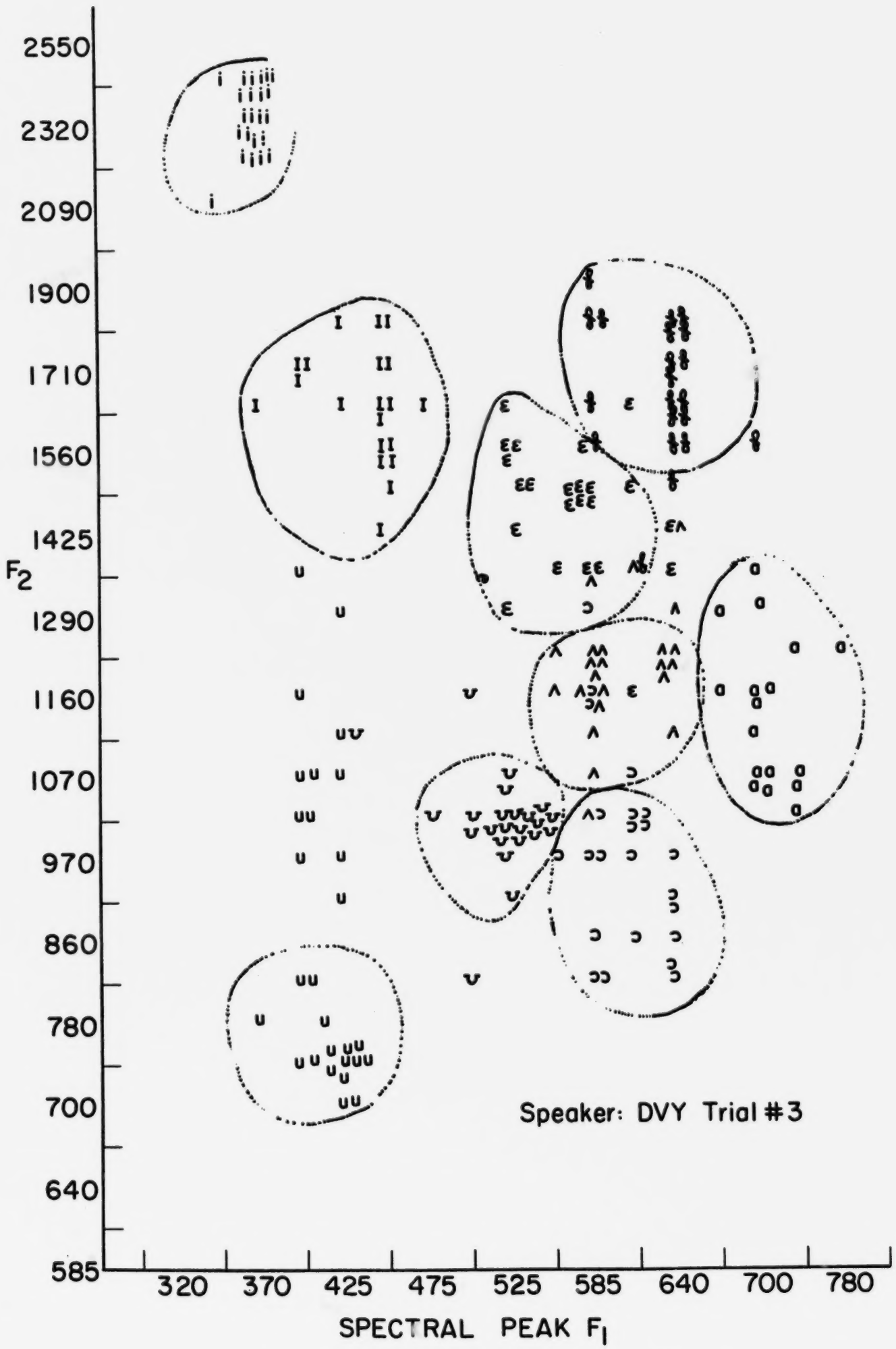
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Fig. 4

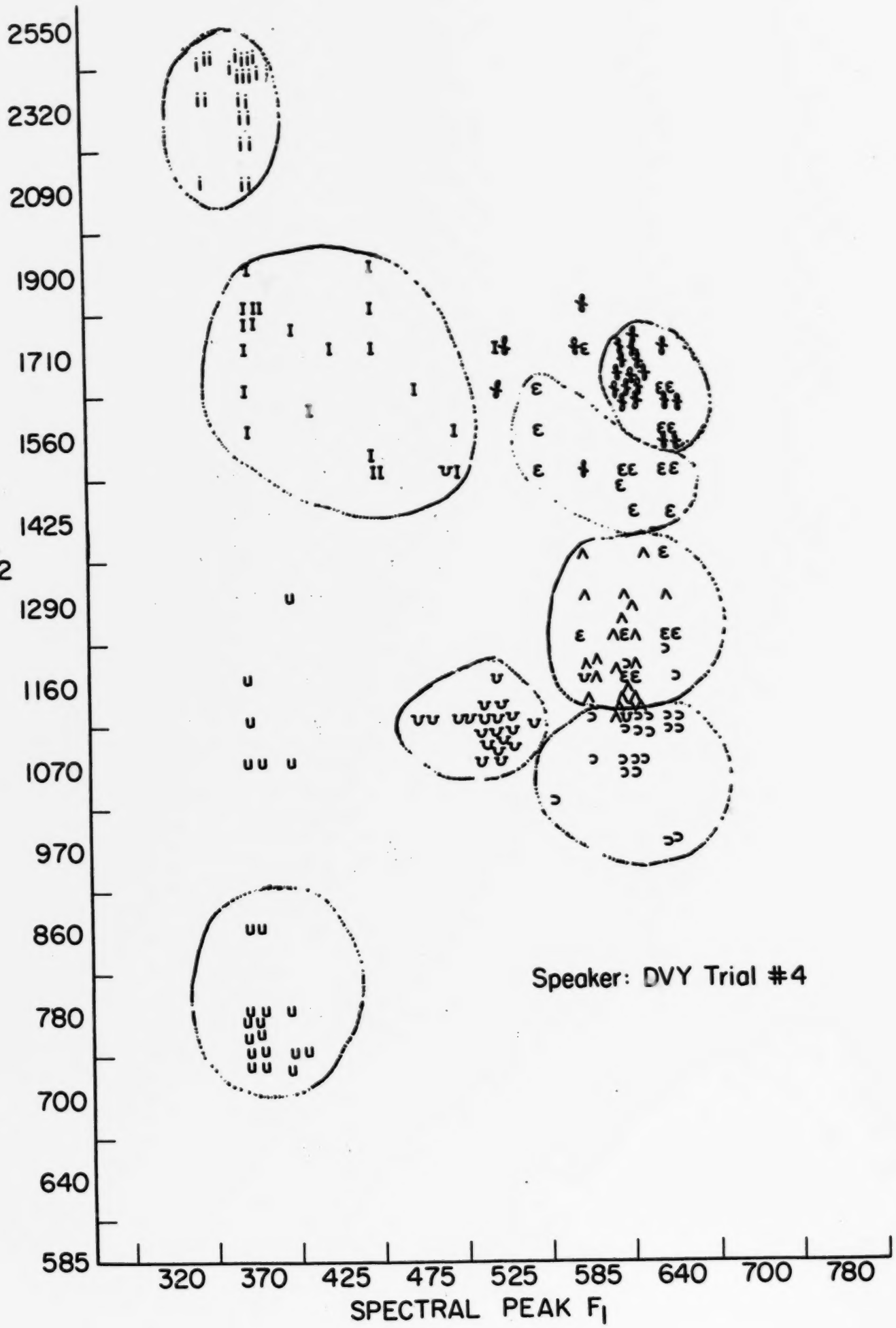
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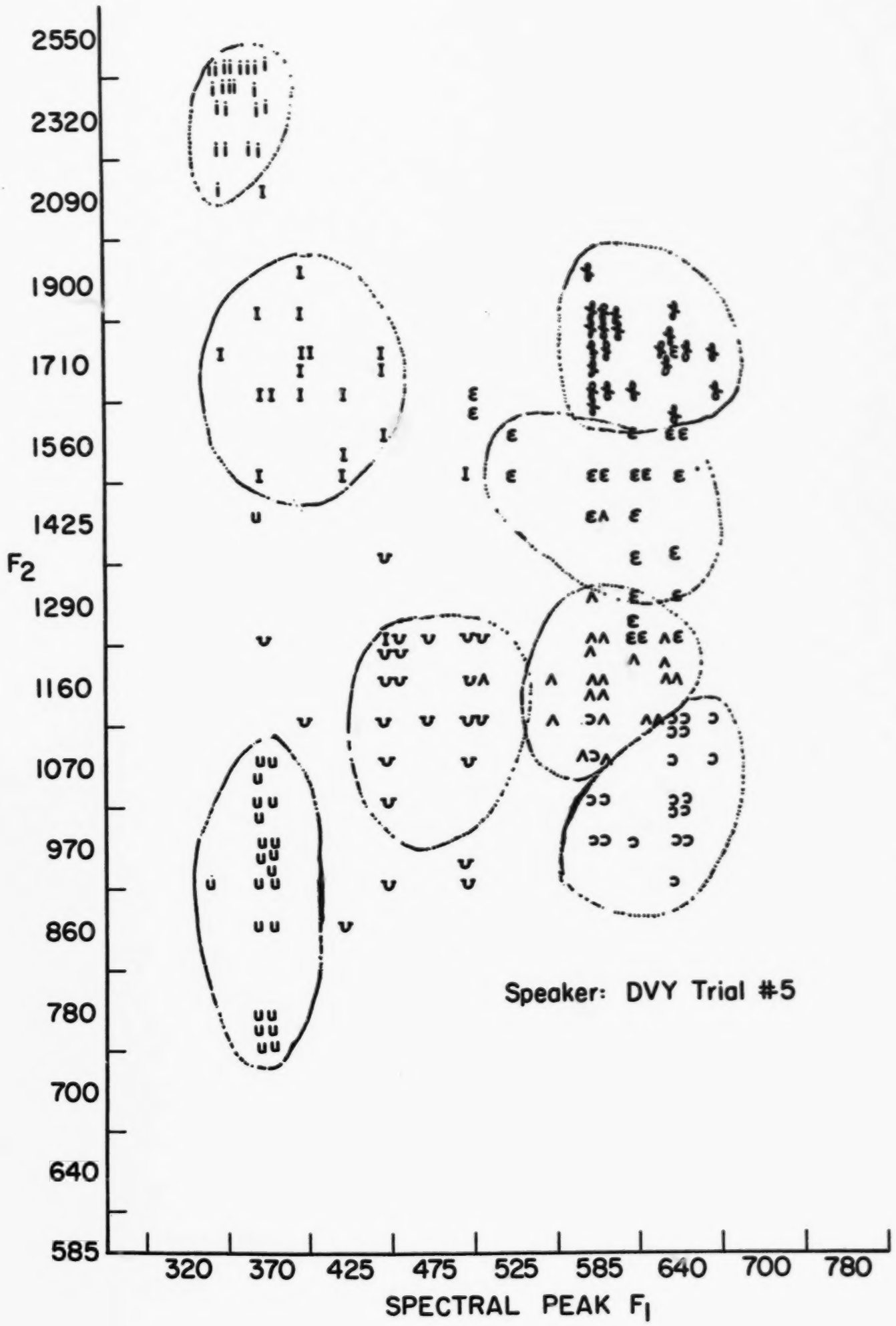
Fig. 5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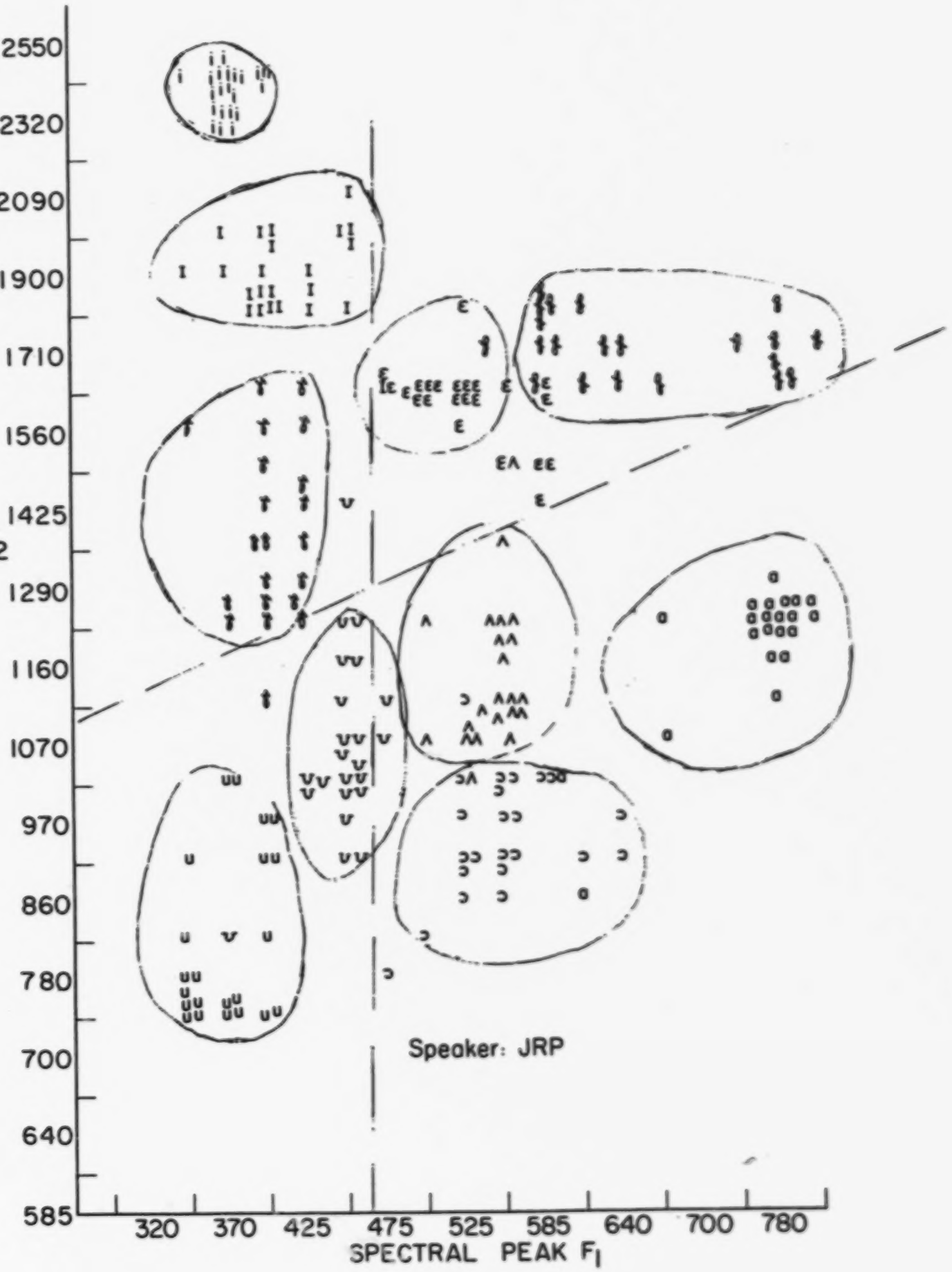
SPECTRAL PEAK F1
Speaker: DVY Trial #5

Fig. 6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320 370 425 475 525 585 640 700 780
SPECTRAL PEAK F1
Speaker: JRP

Fig. 7

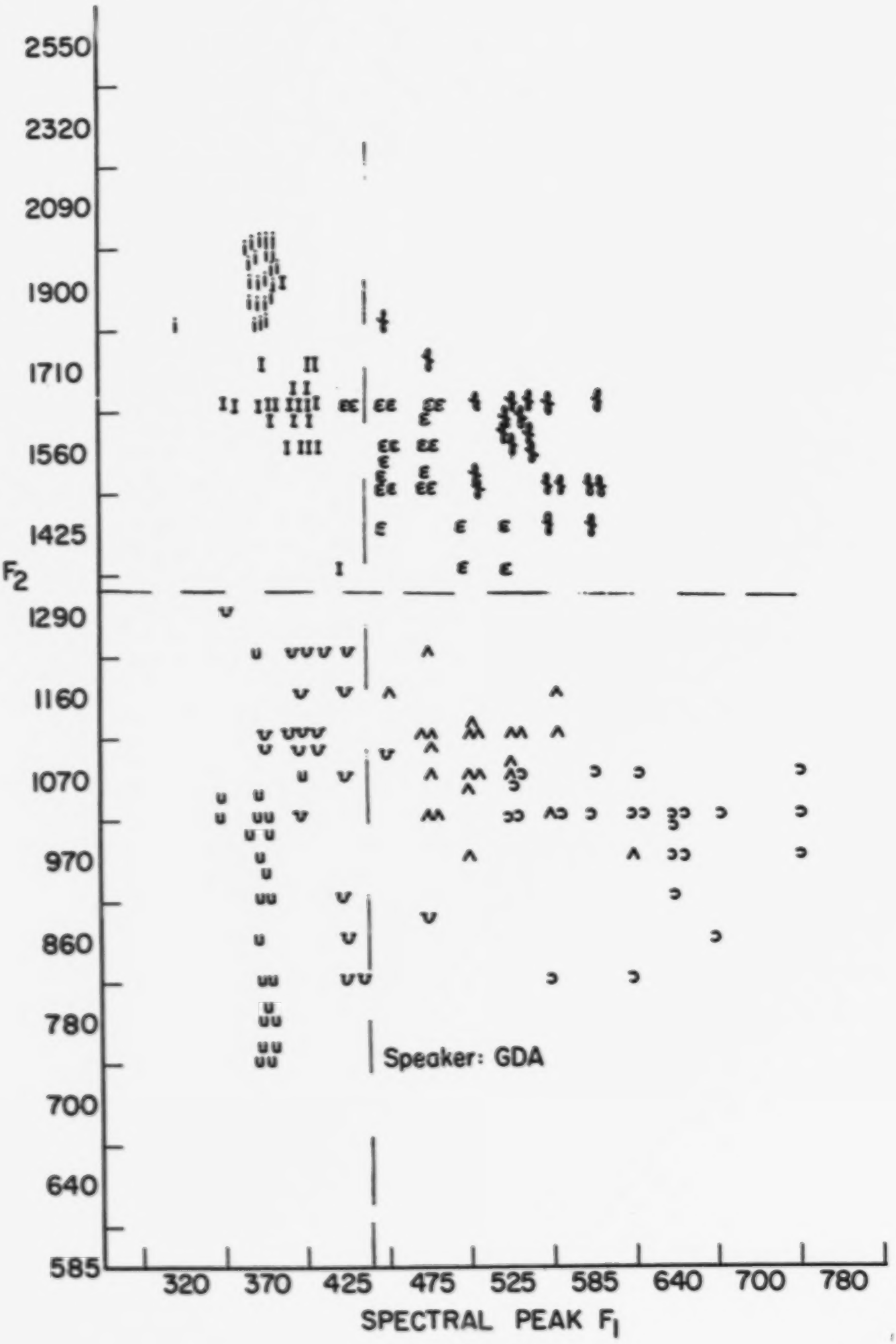
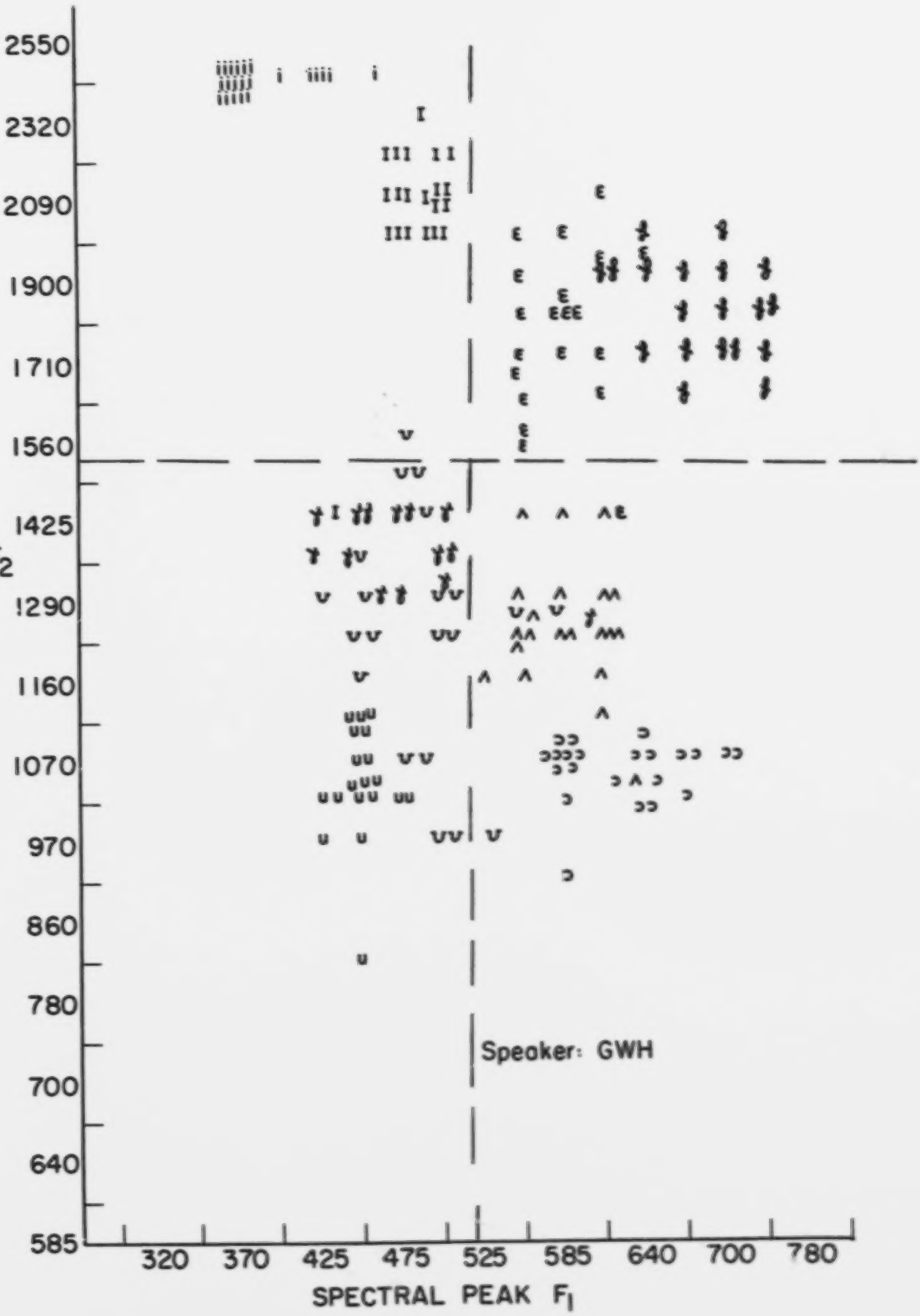

2550
2320
2090
1900
1710
1560
1425
F2
1290
1160
1070
970
860
780
700
640
585
Speaker: GDA
320
370
425
475
525
585
640
700
780
SPECTRAL PEAK F1

Fig. 8

200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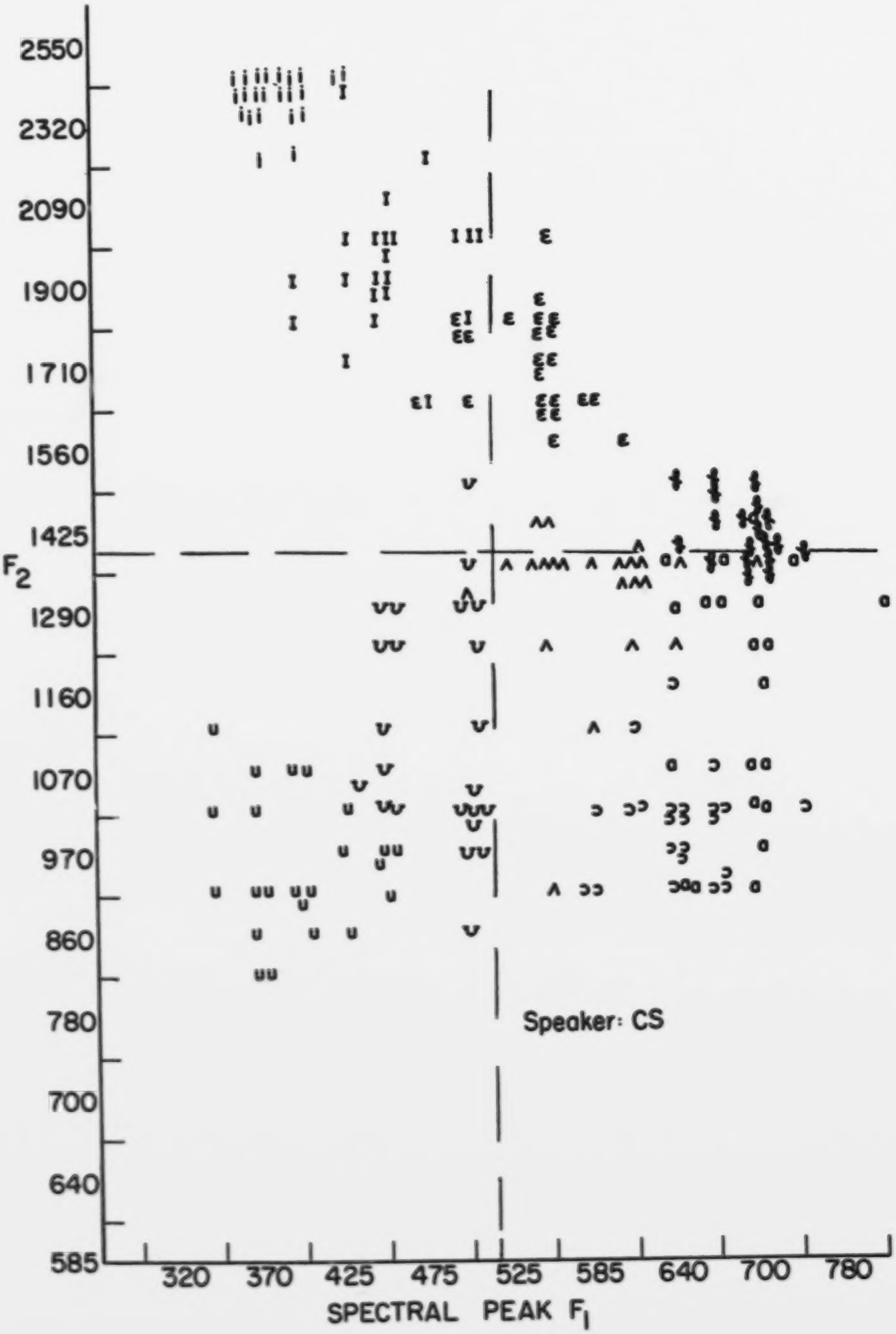
2320
2090
1900
1710
1560
1425
1290
1160
1070
970
860
780
700
640
585
F2
320
370
425
475
525
585
640
700
780
SPECTRAL PEAK F1
Speaker: GWH

Fig. 9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1900
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1560
1425
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1290
1160
1070
970
860
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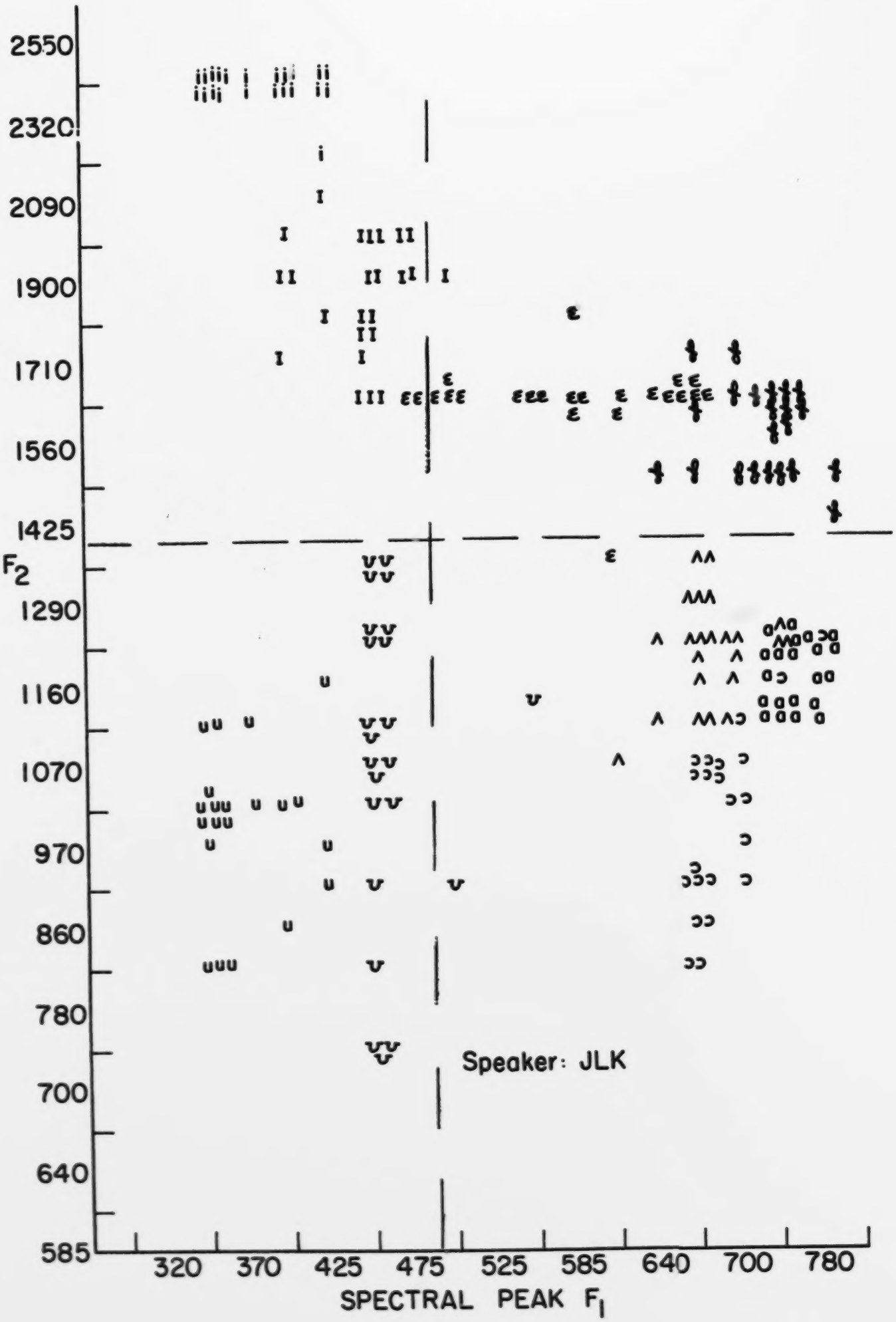
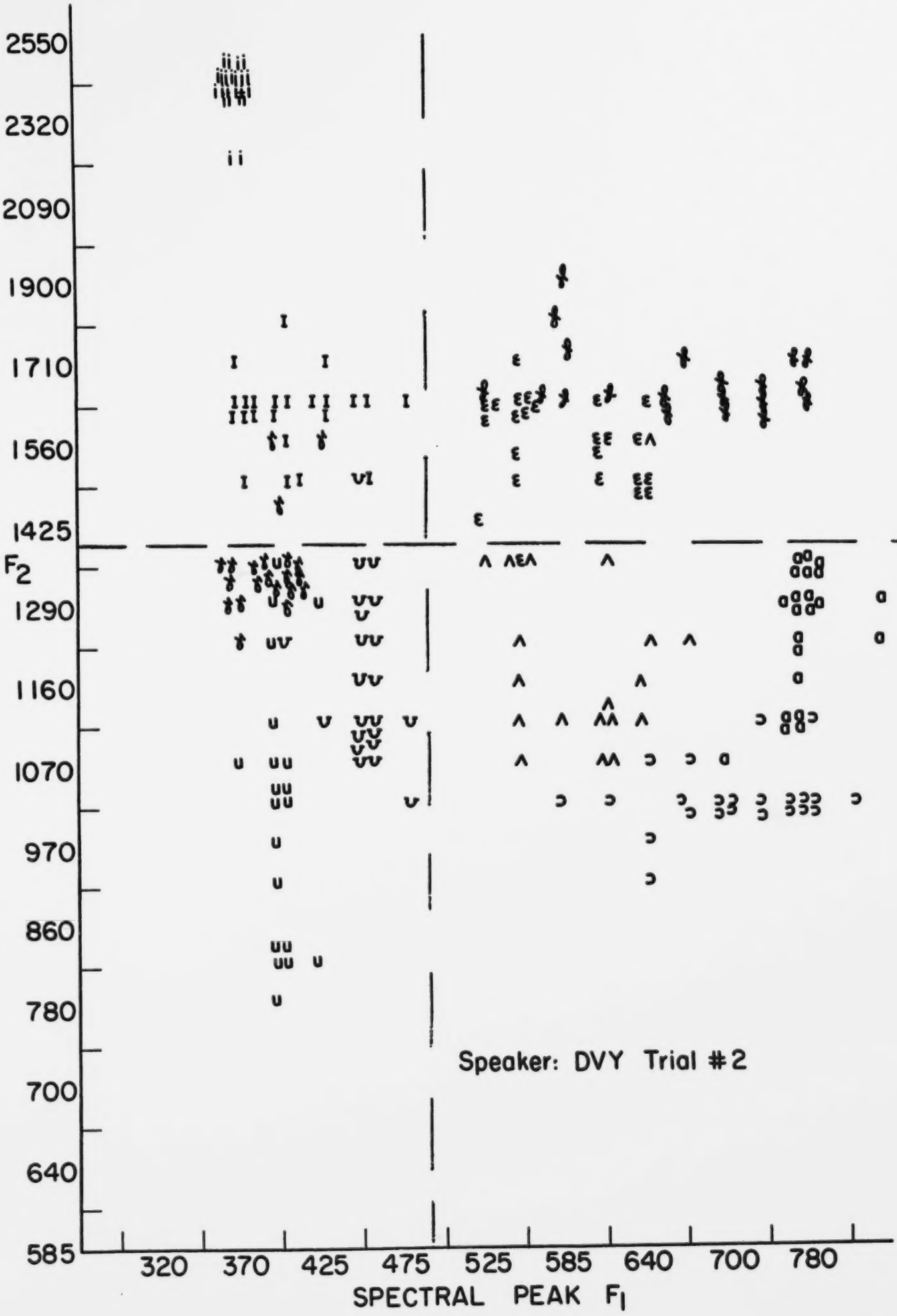
640
585
320
370
425
475
525
585
640
700
780
SPECTRAL PEAK F1
Speaker: CS

Fig. 10


2550
2320
2090
1900
1710
1560
1425
F2
1290
1160
1070
970
860
780
700
640
585
320 370 425 475 525 585 640 700 780
SPECTRAL PEAK F1
Speaker: JLK

203

Fig. 11


2550
2320
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1900
1710
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1425
F2
1290
1160
1070
970
860
780
700
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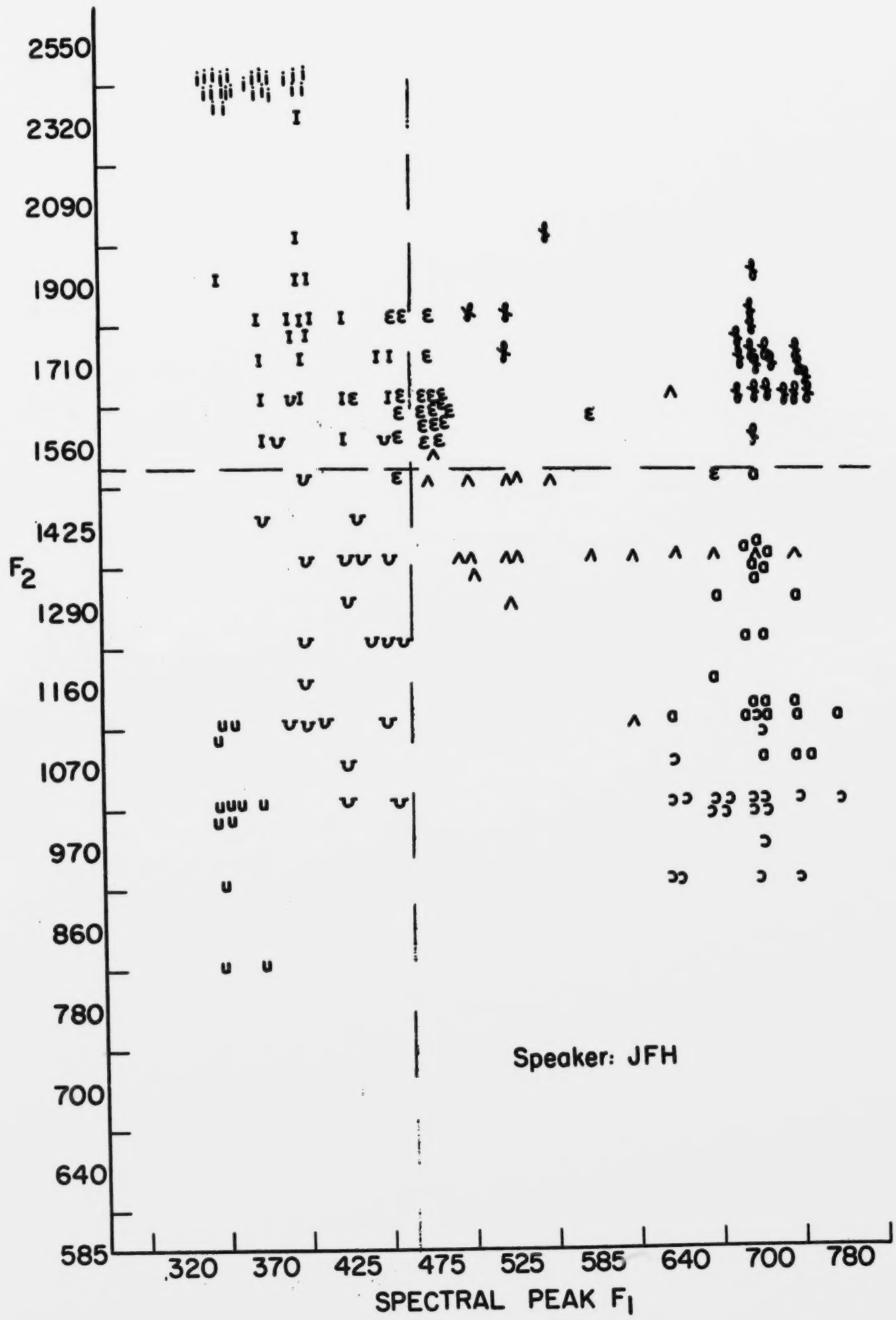
370
425
475
525
585
640
700
780
SPECTRAL PEAK F1
Speaker: DVY Trial #2

204

Fig. 12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1290
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970
860
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700
640
585
F2
320
370
425
475
525
585
640
700
780
SPECTRAL PEAK F1
Speaker: JFH

Fig. 13

Hemdal

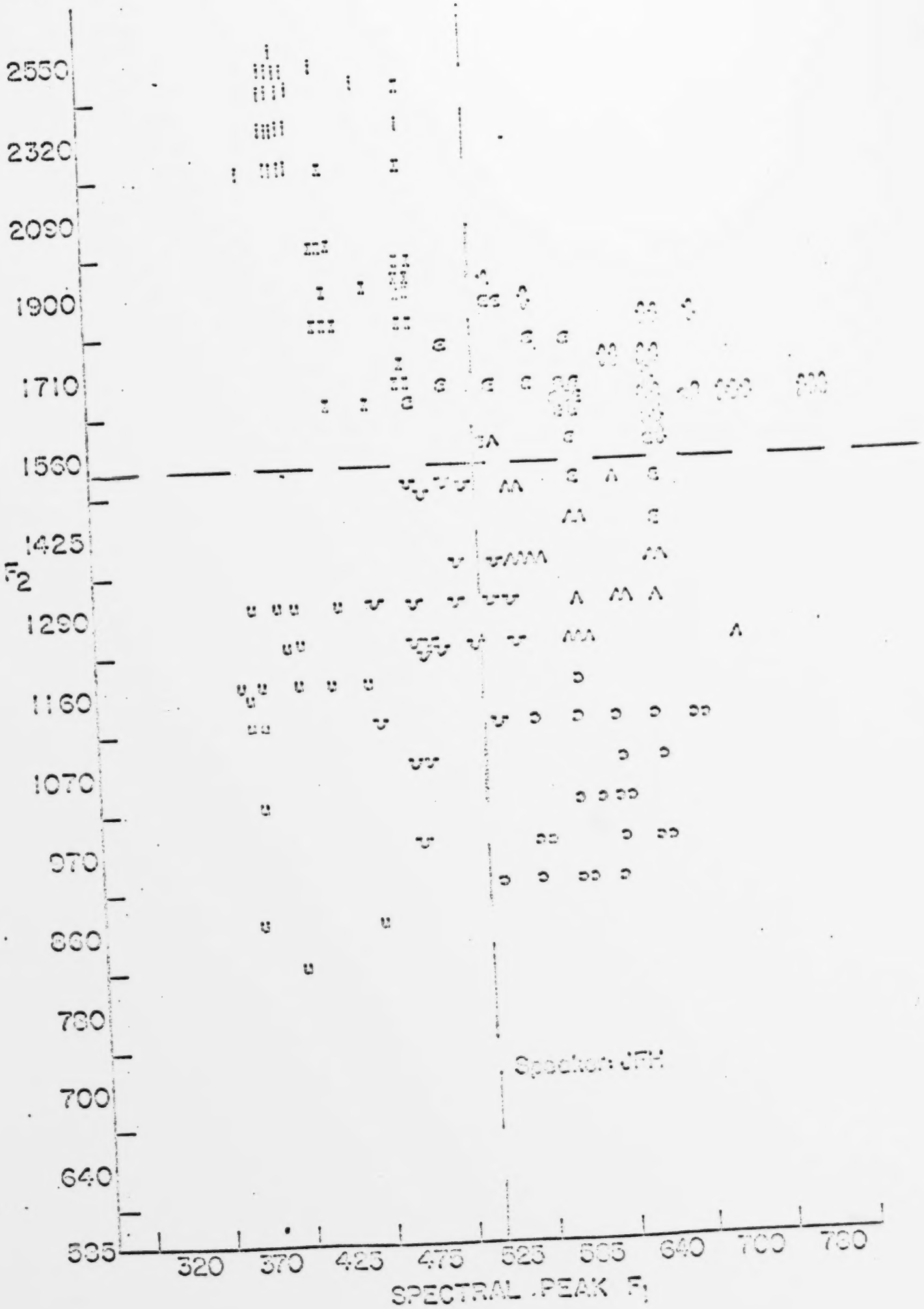

Fig. 14